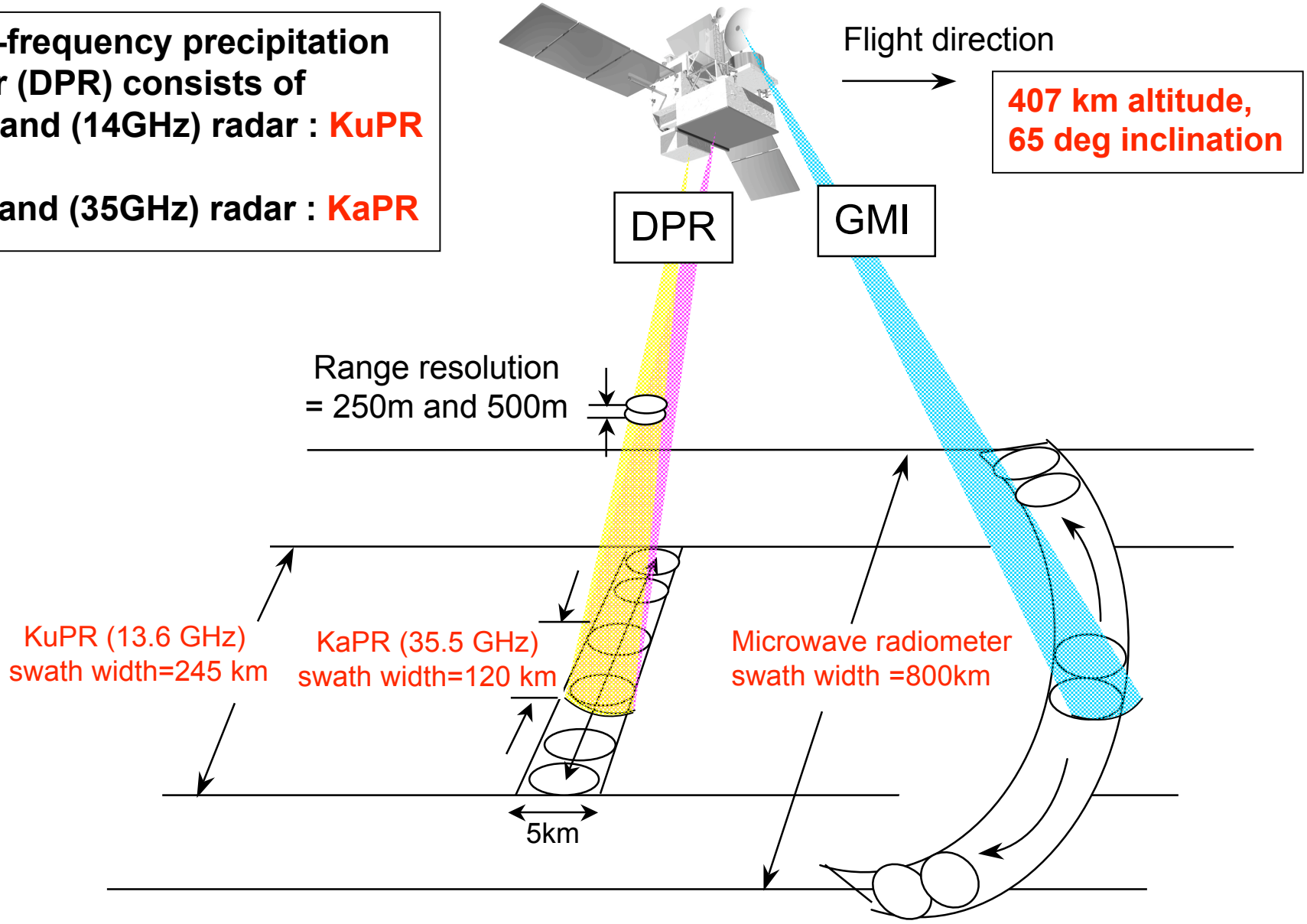
DPR/ GV

- *General features of DPR*
- *DPR products & role of GV*
- *What do we want/expect from gnd-based data*
- *Ku/Ka-band system*
- *Summary*

Concept of precipitation measurement by the GPM core satellite

Dual-frequency precipitation radar (DPR) consists of
Ku-band (14GHz) radar : KuPR
and
Ka-band (35GHz) radar : KaPR



Objectives of DPR

- Three-dimensional observation of precipitation
- High sensitivity measurement of light rainfall and snowfall in high latitude
- Accurate estimation of rainfall rate by combining the Ku- and Ka-band radar data.
- Improvement of MWR's precipitation estimation accuracy using the precipitation parameters (DSD, melting level, rain type, storm height, etc.) estimated by using DPR data.

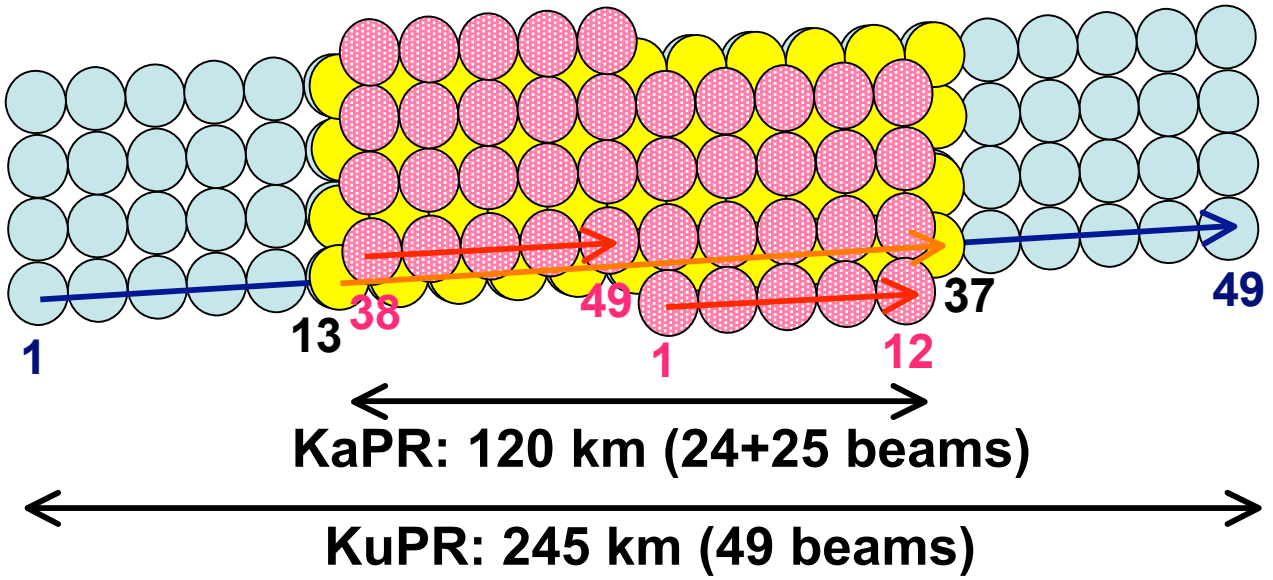
Main Characteristics of DPR

Item	KuPR	KaPR	TRMM PR
Antenna Type	Active Phased Array (128)	Active Phased Array (128)	Active Phased Array (128)
Frequency	13.597 & 13.603 GHz	35.547 & 35.553 GHz	13.796 & 13.802 GHz
Swath Width	245 km	120 km	215 km
Horizontal Reso	5 km (at nadir)	5 km (at nadir)	4.3 km (at nadir)
Tx Pulse Width	1.6 μs (x2)	1.6/3.2 μs (x2)	1.6 μs (x2)
Range Reso	250 m (1.67 μs)	250 m/500 m (1.67/3.34 μs)	250m
Observation Range	18 km to -5 km (mirror image around nadir)	18 km to -3 km (mirror image around nadir)	15km to -5km (mirror image at nadir)
PRF	VPRF (4206 Hz±170 Hz)	VPRF (4275 Hz±100 Hz)	Fixed PRF (2776Hz)
Sampling Num	104～112	108～112	64
Tx Peak Power	> 1013 W	> 146 W	> 500 W
Min Detect Ze (Rainfall Rate)	< 17 dBZ (< 0.5 mm/hr)	< 12 dBZ (500m res) (< 0.2 mm/hr)	< 17 dBZ (< 0.7 mm/hr)
Measure Accuracy	within ±1 dB	within ±1 dB	within ±1 dB
Data Rate	< 112 Kbps	< 78 Kbps	< 93.5 Kbps
Weight	< 365 kg	< 300 kg	< 465 kg
Power Consumption	< 383 W	< 297 W	< 250 W
Size	2.4×2.4×0.6 m	1.44 ×1.07×0.7 m	2.2×2.2×0.6 m

* Minimum detectable rainfall rate is defined by $Ze=200\ R^{1.6}$ (TRMM/PR: $Ze=372.4\ R^{1.54}$)

Concept of the DPR antenna scanning method

- KuPR footprint : $\Delta z = 250$ m
- KaPR footprint (Matched with KuPR) : $\Delta z = 250$ m
- KaPR footprint (Interlaced) : $\Delta z =$ **500 m**



In the interlacing scan area (●), the KaPR can measure snow and light rain in a high-sensitivity mode with a double pulse width.

The synchronized matched beam (●) is necessary for the dual-frequency algorithm.

Types of ground-based experiments

- *Statistical*
  - *Comparisons with satellite over-flight data*
  - *Indirect assessment of errors*
  - *Large data set over different space-time regions*
  - *Emphasis on GPM product validation*
  - *S- or X-band radars (ground-based)*
- *Algorithm Assessment*
  - *Assess microphysical assumptions, analyze error sources*
  - *(spaceborne geometry, surface return can not be tested)*
  - *Better in-situ data for testing*
  - *Emphasis on GPM algorithm testing/ development*
  - *Ku, Ka-band radars (airborne & ground-based)*
  - *(X, W-band also can play a role)*

Comments on DSD estimation from dual-frequency radar

- *Most of the methods are based on: $Z(f_1)/Z(f_2)$ -> D_0*
  - *for rain, attenuation correction is an essential part of algorithm*
  - *Important to understand different correction procedures*

- *Many of the attenuation correction methods for dual-λ (& dual-pol) and can be classified into one of two types*
  - *Integral Equation Approach (depends only on surface to r)*
  - *k-Z (depends on assumptions over full path)*

Comments on DSD estimation from dual-frequency radar

- *For each approach, eq's can be solved either forward or backward*
- *Backward sol'n requires PIA*
- *Forward does not but less robust*
  - *Also, rain retrievals sensitive to CLW, water vapor, mixed phase*
- *Formally, integral eq. approach results in the same set of equations for dual-wavelength and dual-polarization radars*
  - *Same is true for k-Z formulation*

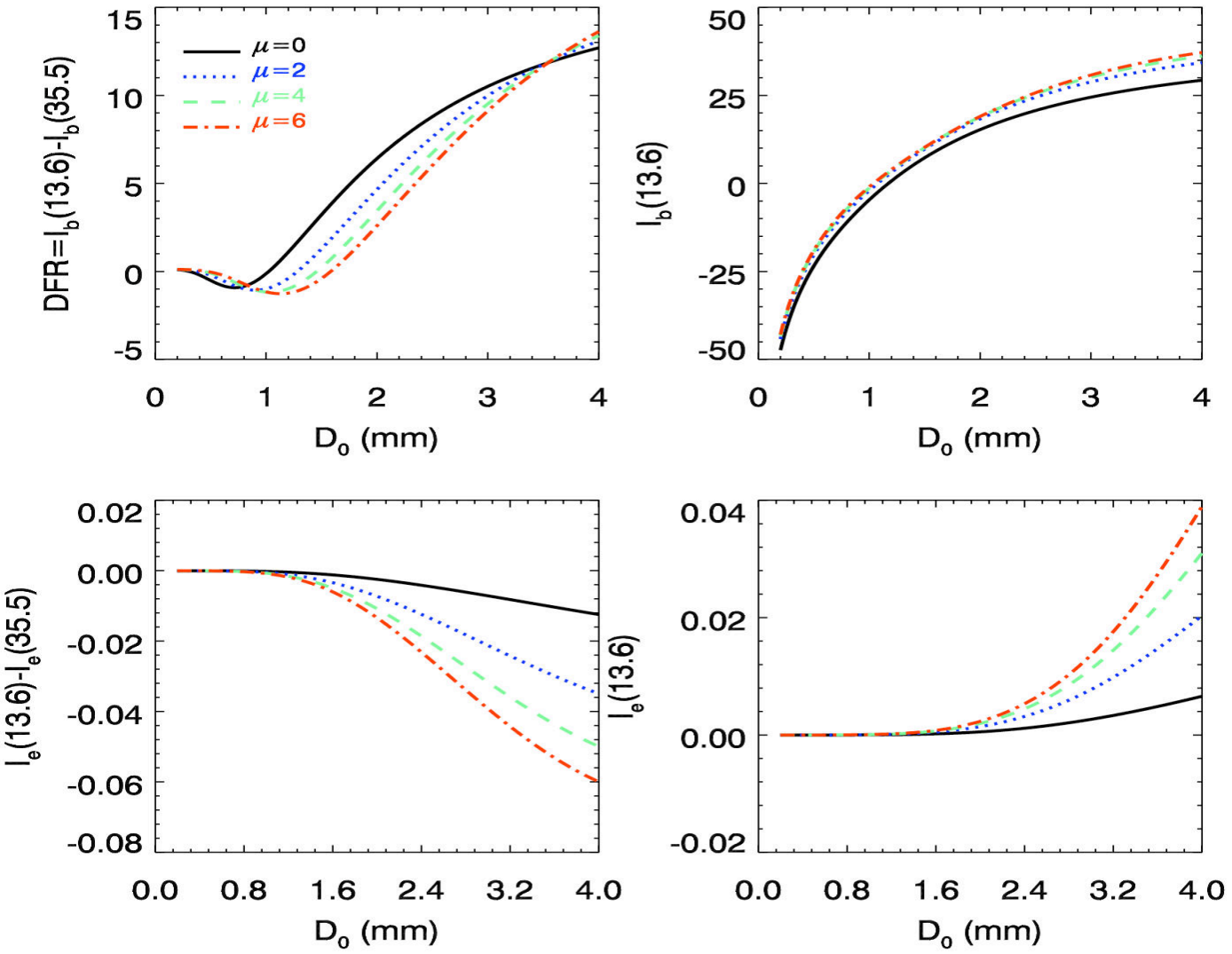
Error Sources in DPR

- *Uncertainties in attenuation estimate*
  - *Errors in estimating total PIA*
  - *Errors in estimating contributions from CLW, water vapor*
- *Mis-identification of hydrometeor type*
- *Scattering characterization of snow/ mixed phase*
- *Mismatched beams*
- *Calibration errors/ inherent signal variability*
- *Errors inherent in retrieval method*
  - *Ambiguity in DFR-D0 relation*
  - *Assumptions regarding form of DSD (μ assumption)*
  - *k-Z, R-Z relations*

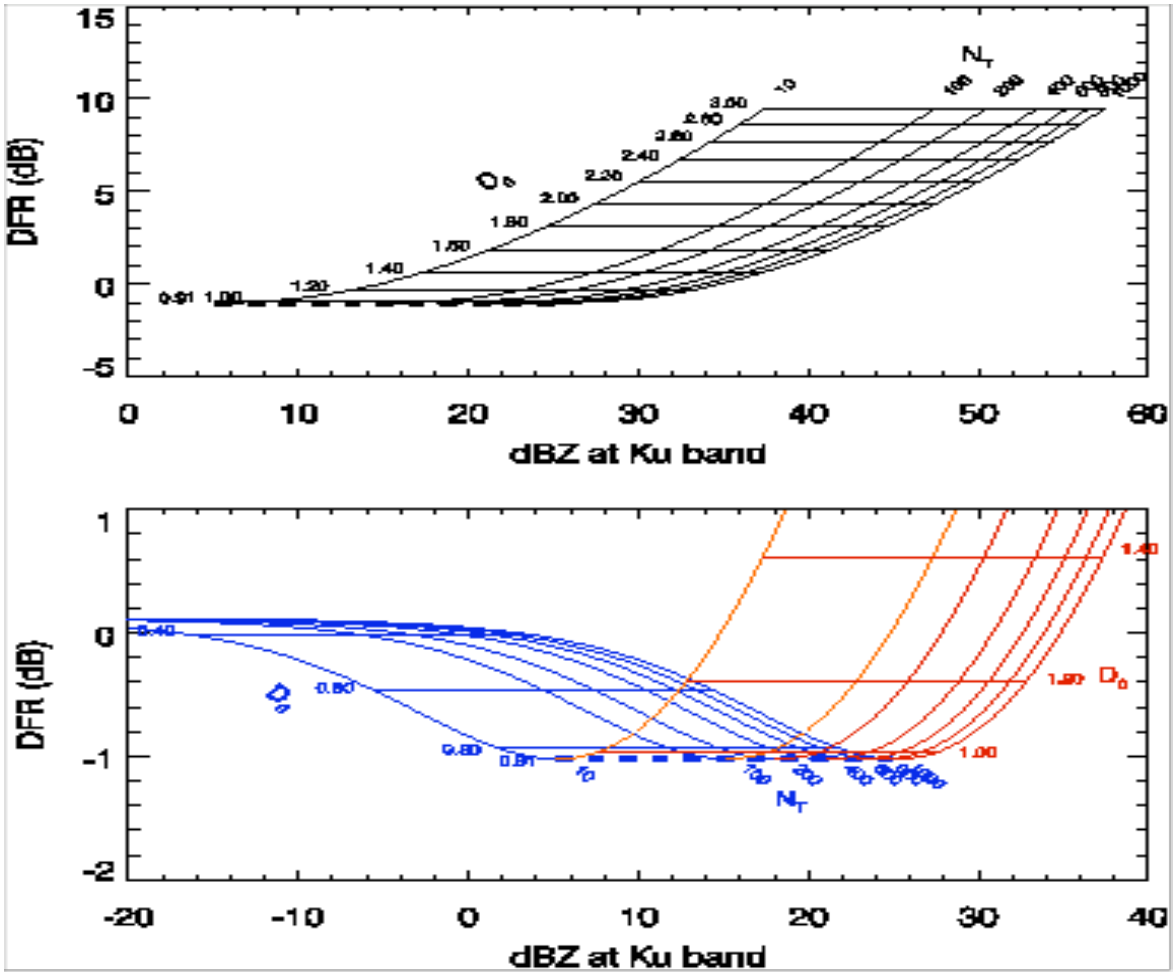
Specific Issues

- *How accurately can PIA be estimated?*
  - *Surface reference (SRT/ DSRT)*
  - *Difference (in range) of differences (in frequency) (dod)*
  - *Radiometer derived*
- *How good are the available retrieval methods ?*
  - *Sensitivity to error sources*
  - *Robustness, range of applicability*
  - *Influence from cloud water, water vapor, mixed phase precip*
- *How can we test their performance?*
- *Can we devise better methods?*

DFR(13.6, 35.5 GHz) & associated quantities



DSD estimation



Airborne vs Ground-based validation data

- *Near-nadir airborne data provides similar geometry & measurements to spaceborne*
  - *Top down vs bottom up is important distinction when attenuation is present*
  - *Surface return is an important comp. of sp. algorithms*
- *For gnd-based, near-horizontal*
  - *Polarimetric & multi-wavelength alg's can be used*
  - *Validation of retrievals by in-situ instruments much easier to perform*
  - *For validation/comparison, only gnd-based provide sufficient coverage for statistical robustness with satellite data retrievals*

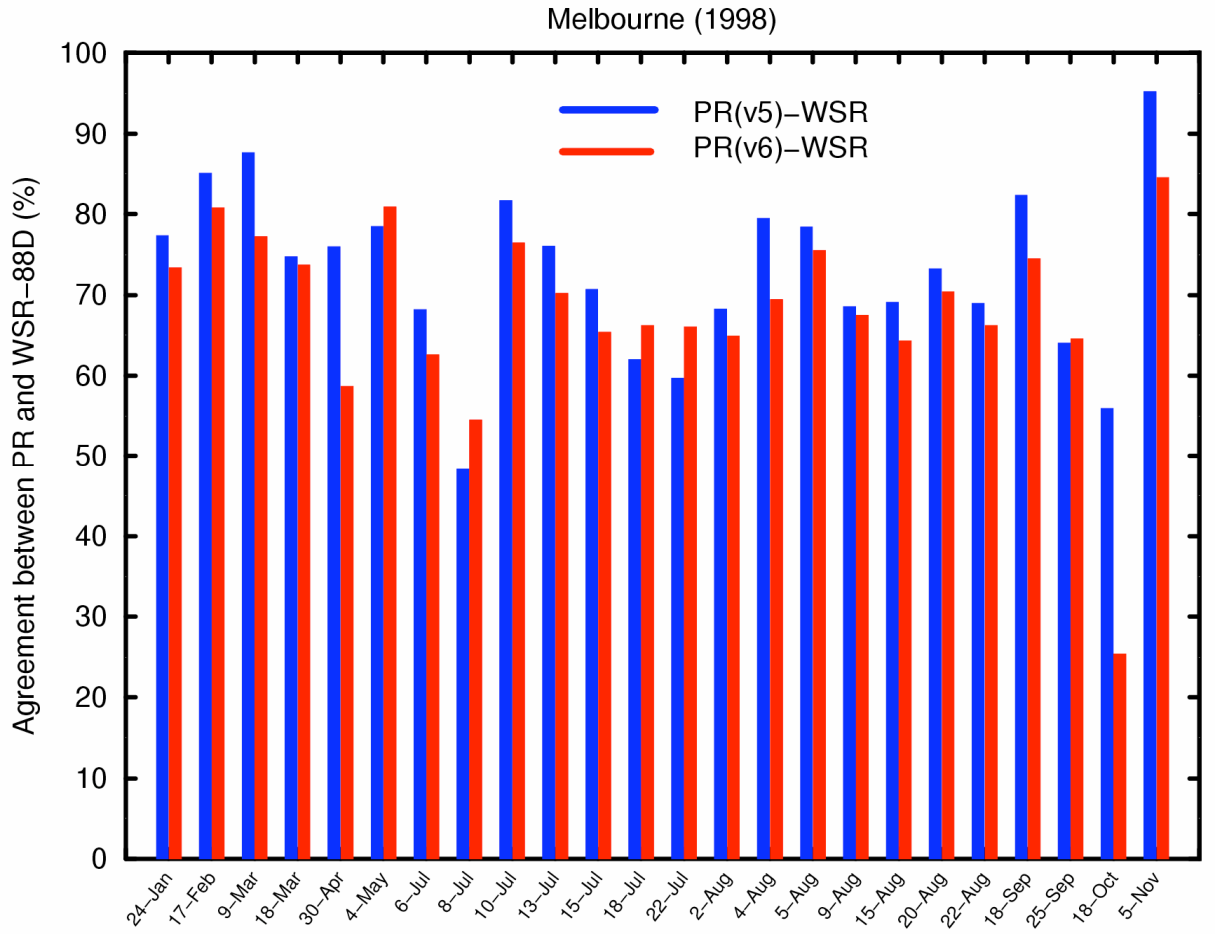
DPR products & validation

- *Rain/no-rain flag*
  - *17 dBZ for TRMM PR*
  - *12 dBZ for DPR*
    - *12 dBZ for Ka-band low-resolution mode*
    - *17-18 dBZ for Ku/Ka-band standard mode*
  - *Over ±36^0 lat, ~3% rain volume missed*
  - *For GPM, at high latitudes, probably larger*
  - *Low-level precip especially at swath edge is missed by PR/DPR*
    - *At Ku-band swath edge, rain from ~1.6 km to surface is missed*
- *GV radars should do much better*
  - *However, strong range dependence*
  - *Some issues for near-surface rain/ beamfilling*

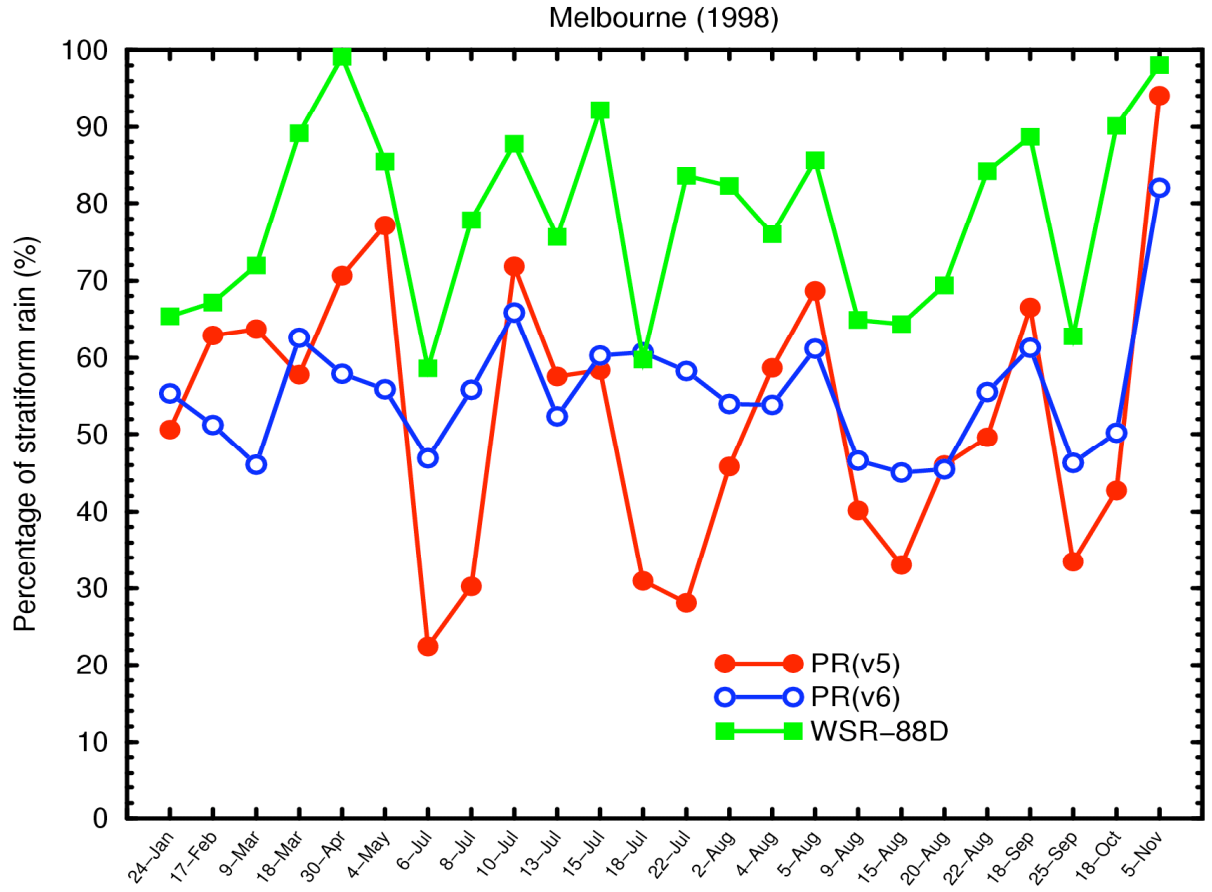
DPR products & validation

- *Rain-type classification*
  - *Stratiform/ convective/ other*
    - *Vertical & horizontal methods both used*
    - *Output indicates results from V, H methods*
  - *Detection (and height) of bright band*
  - *Storm height (17 dBZ) determination*
- *Comparisons between PR/GV classifications show relatively poor agreement*
  - *Disagreement caused by poor vertical structure?*
  - *Caused by using Z w/o attenuation correction?*

Storm Type Classification

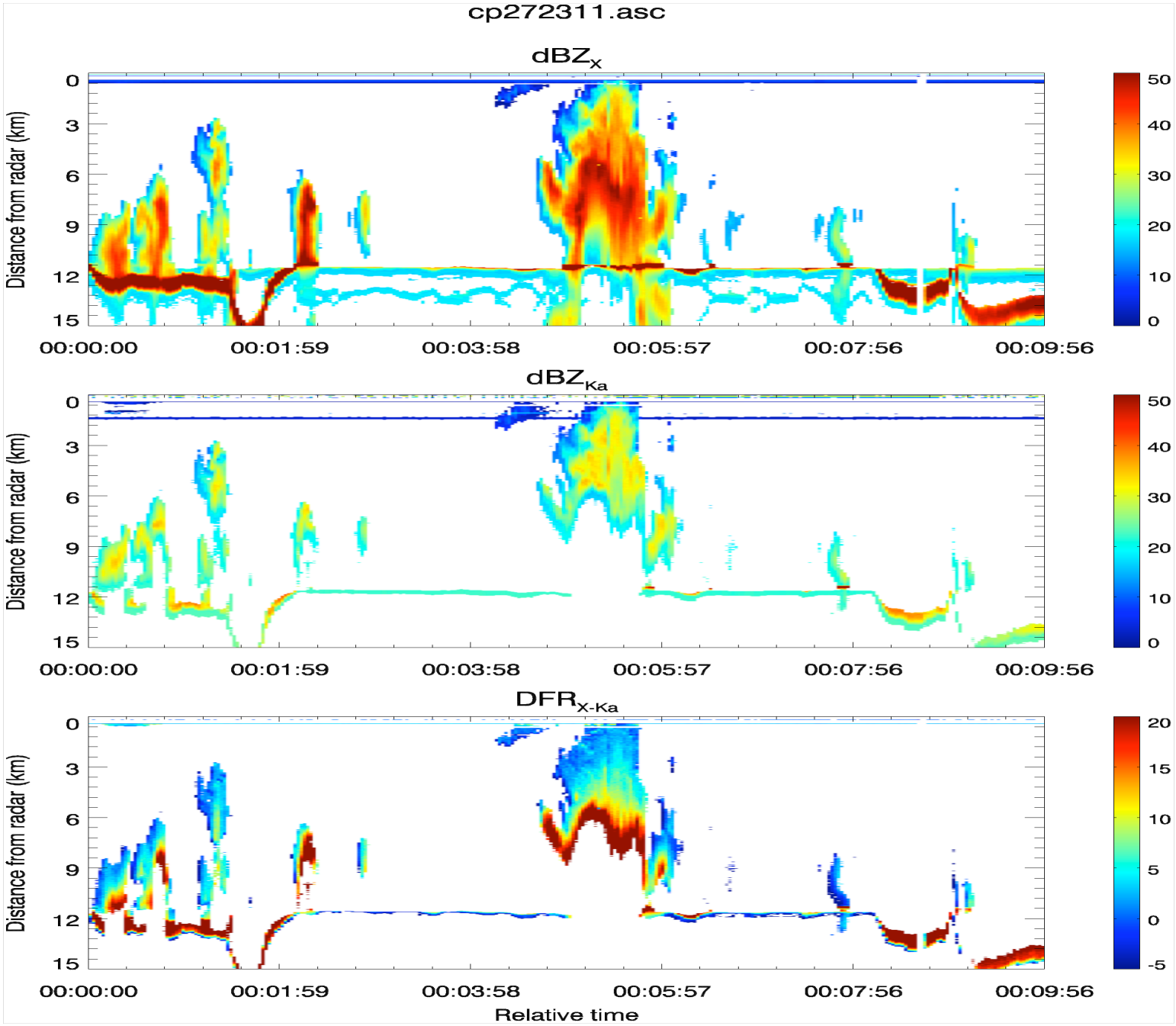


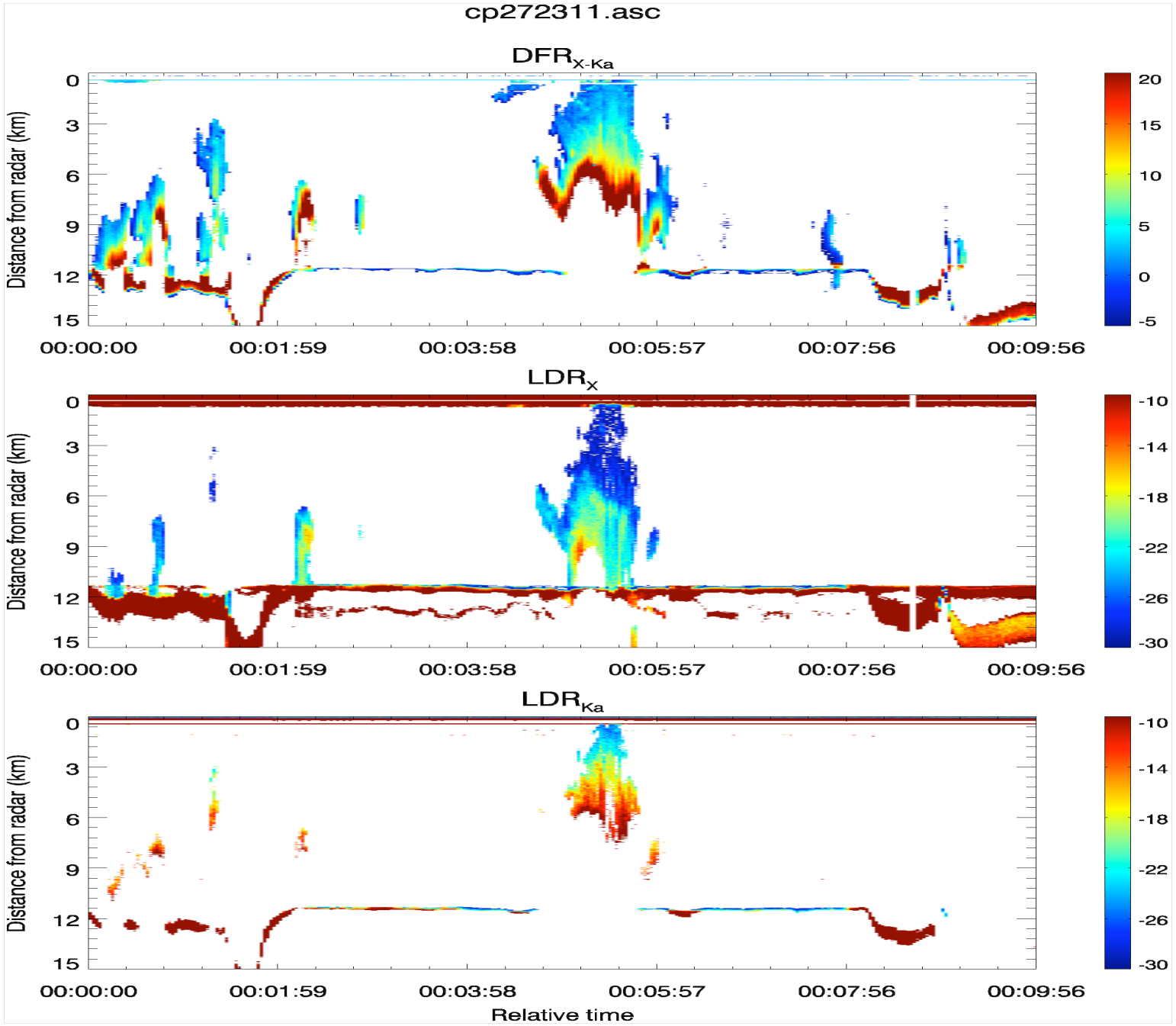
Percentage of Stratiform Rain



DPR products & validation

- *Hydrometeor Identification*
  - *Identify regions of frozen, mixed phase, liquid*
  - *DPR may have difficulty in convective rain*
    - *Sharp increase in DFR may help detect top of mixed-phase layer*
    - *More difficult to detect trailing edge*
  - *Even if accurate detection of mixed-phase region*
    - *Modeling of scattering/attenuation for MP not easy*
- *GV polarimetric radar data should be useful*
  - *Classification schemes have been developed*
  - *Use to validate DPR classification algorithms*
  - *Can the data also be used to assess potential effects of multiple scattering at Ka-band?*


cp272311.asc
dBZX
dBZKa
DFRX-Ka
Distance from radar (km)
0
3
6
9
12
15
00:00:00
00:01:59
00:03:58
00:05:57
00:07:56
00:09:56
Relative time
50
40
30
20
10
0
20
15
10
5
0
-5


cp272311.asc
DFR X-Ka
LDR X
LDR Ka
Distance from radar (km)
0
3
6
9
12
15
00:00:00
00:01:59
00:03:58
00:05:57
00:07:56
00:09:56
Relative time
20
15
10
5
0
-5
-10
-14
-18
-22
-26
-30

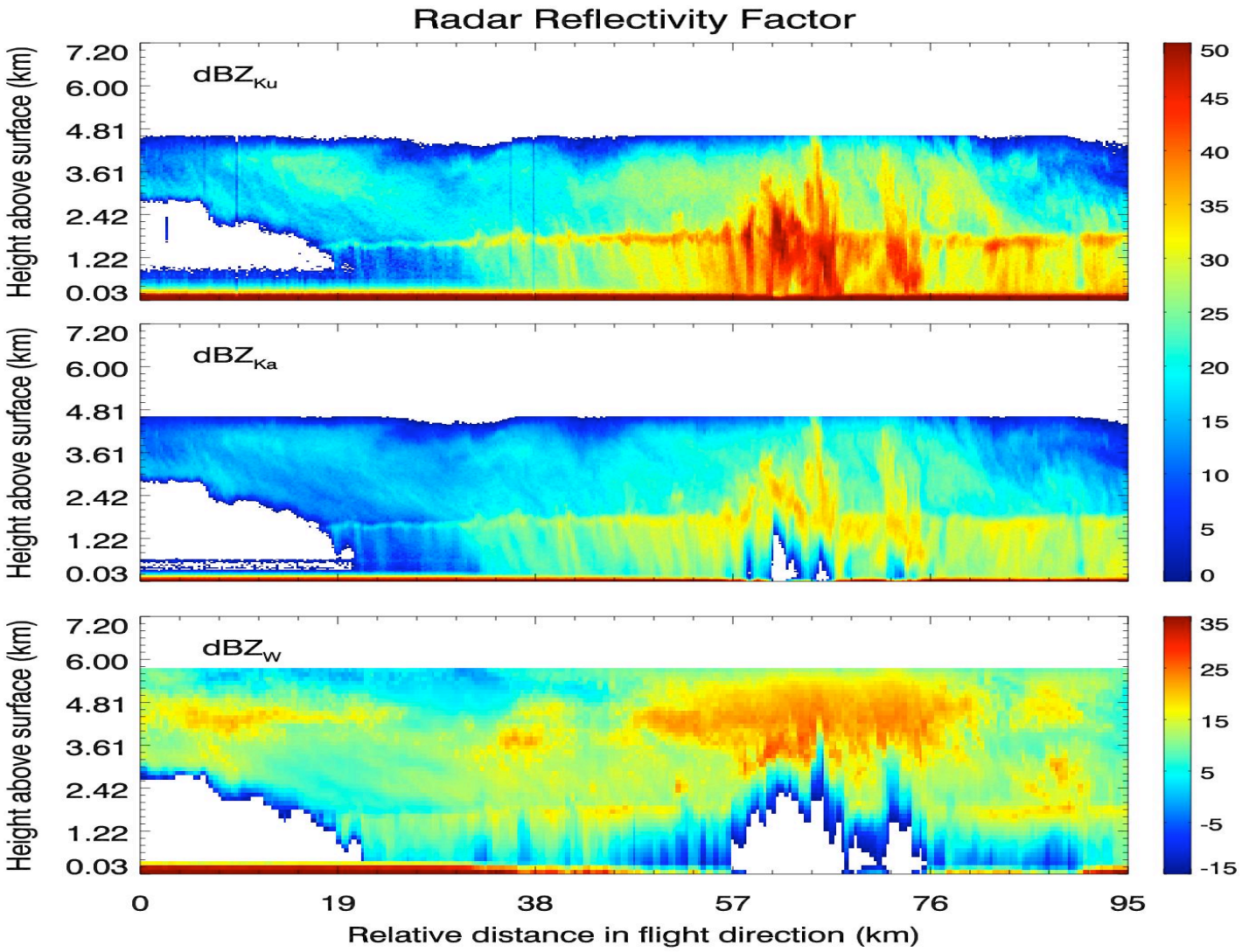
DPR products & validation

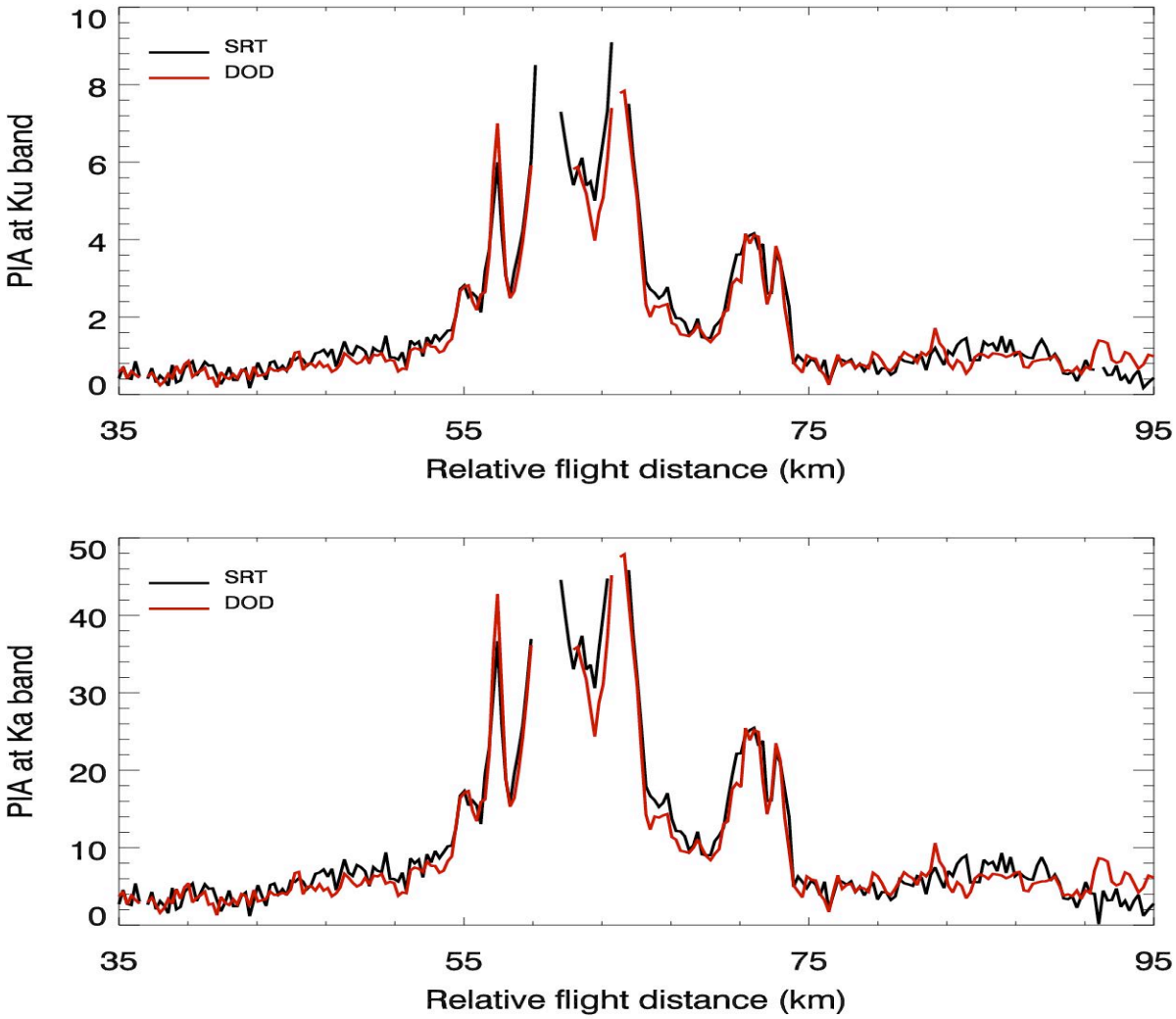
- *Other atmospheric constituents*
  - *Cloud liquid water, water vapor*
  - *DPR retrievals need to depend on models or ancillary data (from GMI?)*
  - *Any information from ground sensors should be useful*
    - *multi-channel radiometer (?)*
  - *Uncertainties arising from mixed-phase, cloud water suggest use of backward-going methods*
    - *Retrievals influenced only by ranges from surface to r*
    - *These methods, however, require PIA at both wavelengths*

DPR products & validation

- *PIA estimates (SRT, DSRT, δZ_{surf})*
  - *Indirect comparisons*
    - *Compare at different heights*
    - *$Z_{SB}(Ku) \leftrightarrow Z_G(Ku)$, $Z_{SB}(Ka) \leftrightarrow Z_G(Ka)$*
    - *If ground radar is at diff wavelength, must account for non-Rayleigh scattering (requires DSD information)*
    - *Poor agreement near surface suggests errors in DPR attenuation correction*
  - *Direct comparisons*
    - *Resample ground radar data along DPR beams*
    - *Requires estimate of attenuation by ground radar in mixed phase region and by cloud water, water vapor*

JPL PR-2, UMass ACR: Wakasa Bay, 19 Jan 2003

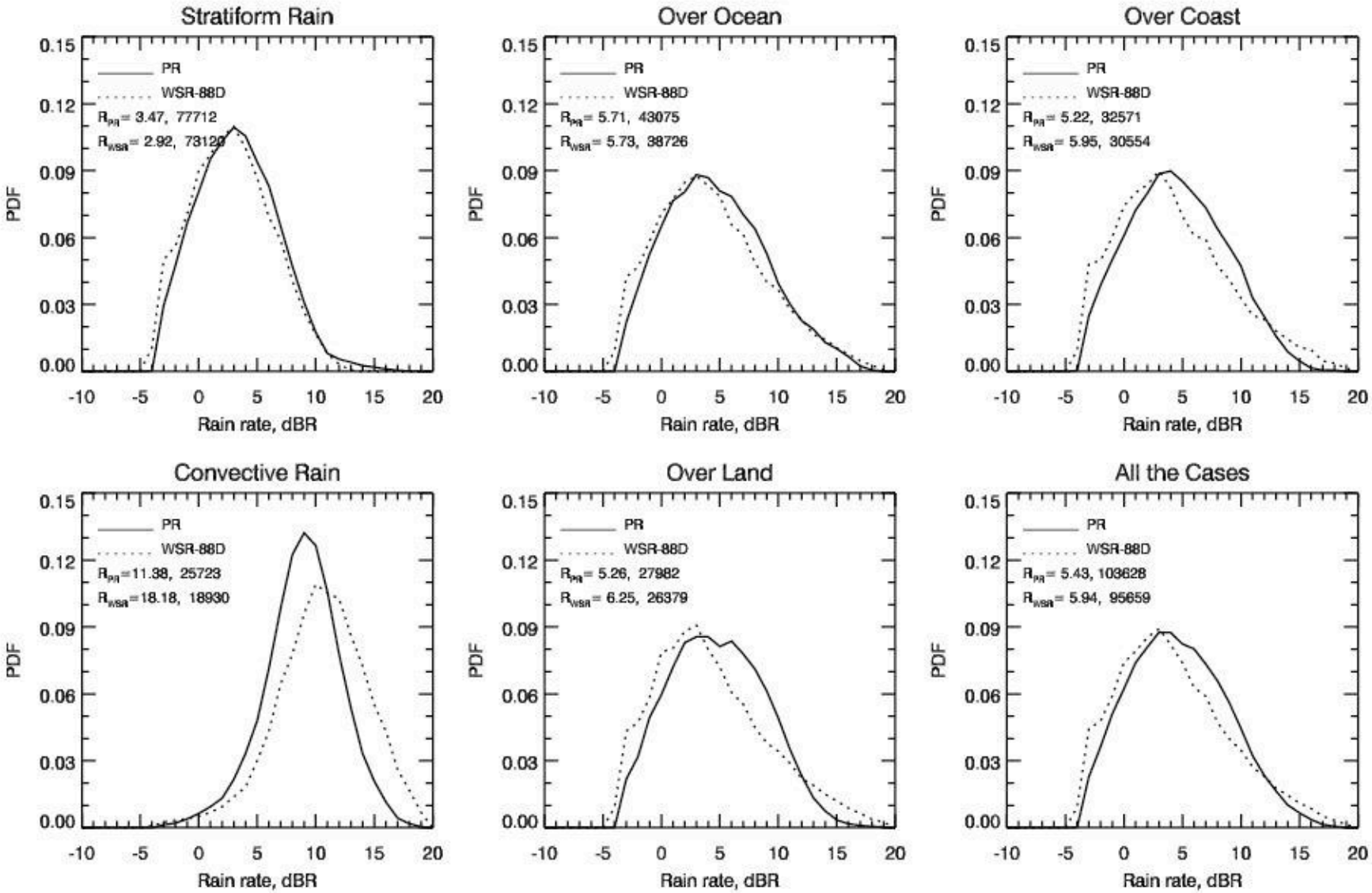



SRT
DOD
PIA at Ku band
0
2
4
6
8
10
35
55
75
95
Relative flight distance (km)
SRT
DOD
PIA at Ka band
0
10
20
30
40
50
35
55
75
95
Relative flight distance (km)

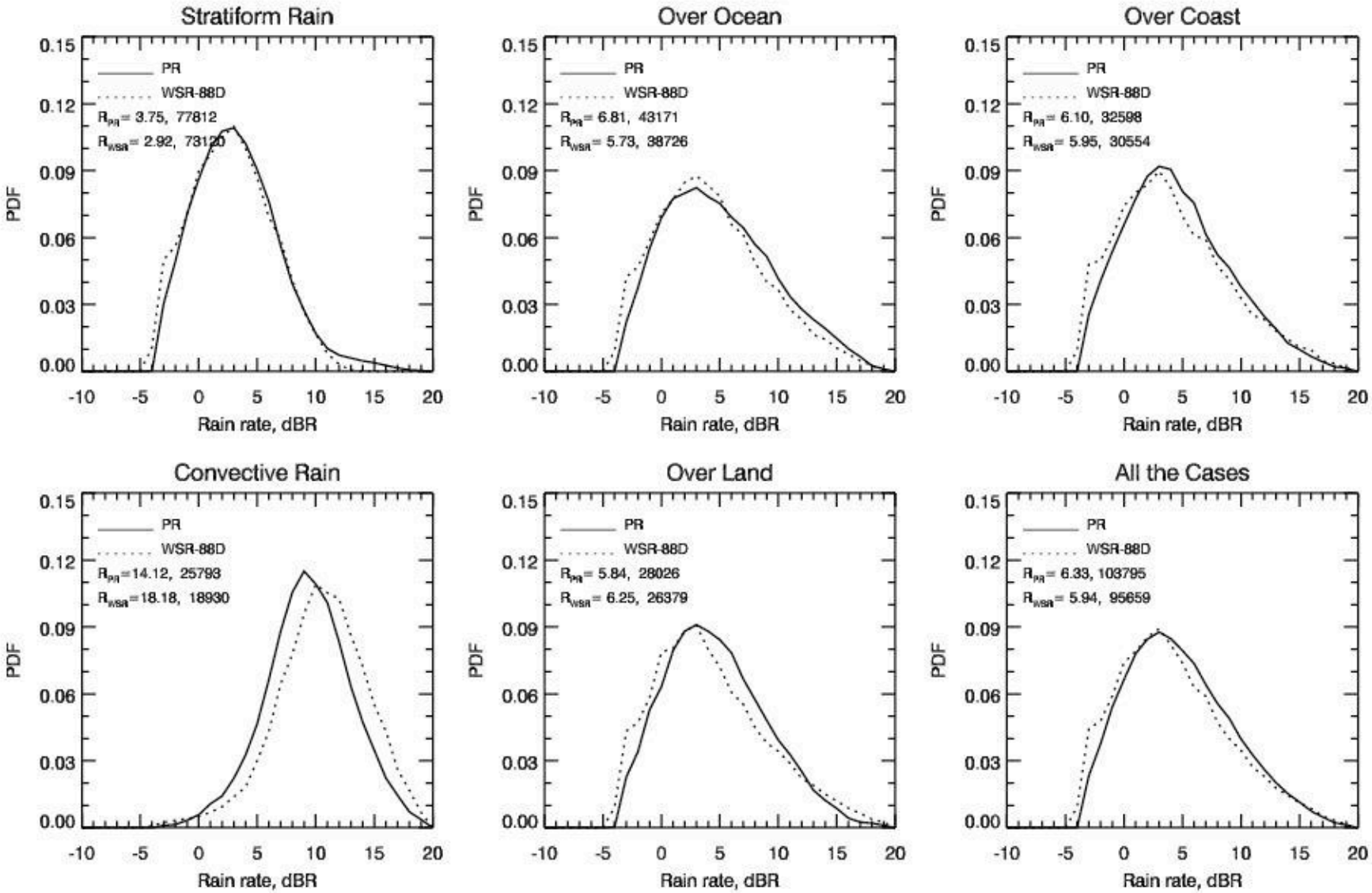
DPR products & validation

- *Z comparisons*
  - *Need to account for freq dependence*
  - *Important to do comparisons at different heights*
- *R, M comparisons*
- *D_0, N_t, (μ) comparisons*
  - *Number conc. & μ are difficult to estimate*
  - *D_0 - μ (or Λ- μ) still controversial*
  - *In snow, ρ (mass density) is important*

TRMM PR vs. WSR-88D during v6_98-0702 in MELB(Unconditional rain with threshold of R_{min}=0.5 mm/h)



TRMM PR vs. WSR-88D during v6_98-0702_john_1 in MELB(Unconditional rain with threshold of R_{min}=0.5 mm/h)



What kinds of products do we want from ground instruments (for validation)?

- *3D estimates of DSD (rain, snow) over significantly large spatial domain from a sufficient number of sites*
  - *Different climatologies*
  - *Land and Ocean backgrounds*
- *M, R, Z over same domain*
- *Hydrometeor identification*
- *Rain/no-rain flag*

What kinds of info do we want for algorithm testing?

- *Tests of DPR candidate algorithms*
  - *Comparisons with polarimetric retrievals*
  - *Comparisons with in-situ measurements*
- *Assessment of algorithms errors*
  - *Hydrometeor identification*
    - *DFR vs polarimetric*
  - *Cloud water & mixed phase*
  - *Influence on PIA accuracy on retrievals*
- *Assessment of multiple scattering at Ka-band*

What kinds of products do we expect

- *S-band pol:*
  - *Good spatial coverage, low attenuation, polarimetric retrievals limited to higher R*
- *X-band pol*
  - *Somewhat restricted spatial coverage, moderate attenuation, extend pol retrievals to lighter R*
- *Ku-band, Ka-band*
  - *Restricted spatial coverage, moderate-high attenuation, extend pol retrievals to smaller R*
  - *Directly relevant to DPR algorithm performance*
- *Polarimetric data may not be useful quantitatively for mixed-phase, frozen hydrometeors*
- *Dual/triple-wavelength data could be useful in these regions*

Some Ku/Ka-band Requirements (R. Cifelli)

- *freq: ~ 13.6, 35.5 GHz*
- *HPBW: ≤ 1^0*
- *range resolution: ≤ 50 m*
- *Maximum range: ≥ 40 km*
- *measurements at each freq*
  - *$Z_{h,v}$ ± 1dB, ϕ_{dp} ± 3^0 ρ_{hv} ± 0.005*
  - *LDR ± 1dB, v_{dop} ± 1 m/s*
- *Products*
  - *κ_{dp}, M, R, D_0, N_t, hydro ID,*
- *Scanning & pointing angle requirements*
- *Resampling & temporal requirements*

Potential uses of Ku/Ka-band radar

- *Test dual-wavelength, dual-pol methods with same set of data*
  - *Use ϕ_{dp} to estimate PIA*
  - *Compare DSD, R estimates from both approaches*
  - *Use in-situ data to validate*
  - *Investigate dual-wavelength retrievals of snow/ mixed phase*
- *Test radar/radiometer retrievals*
  - *Acquire data in near-zenith mode*
  - *Test retrievals with & w/o radiometric data*
- *Component in nested radar network*
  - *Comparisons with X-band, S-band pol data*
  - *Evaluation of potential for polarimetry at Ku/Ka-band*

Summary

- *Ku/Ka-band radar should be useful in DPR algorithm development & testing*
  - *Polarimetric/dual-wavelength both provide microphysical info*
  - *In contrast to airborne data, in-situ validation (disdrometers/gauges) can be obtained on routine basis*
- *Makes sense as part of a larger radar network*
  - *nested deployment with S- or X-band pol radar*
- *Need to assess existing dual-wavelength polarimetric radars*
  - *Can existing systems/ data sets satisfy needs of GPM?*
  - *Can radars presently under development meet needs of GPM?*

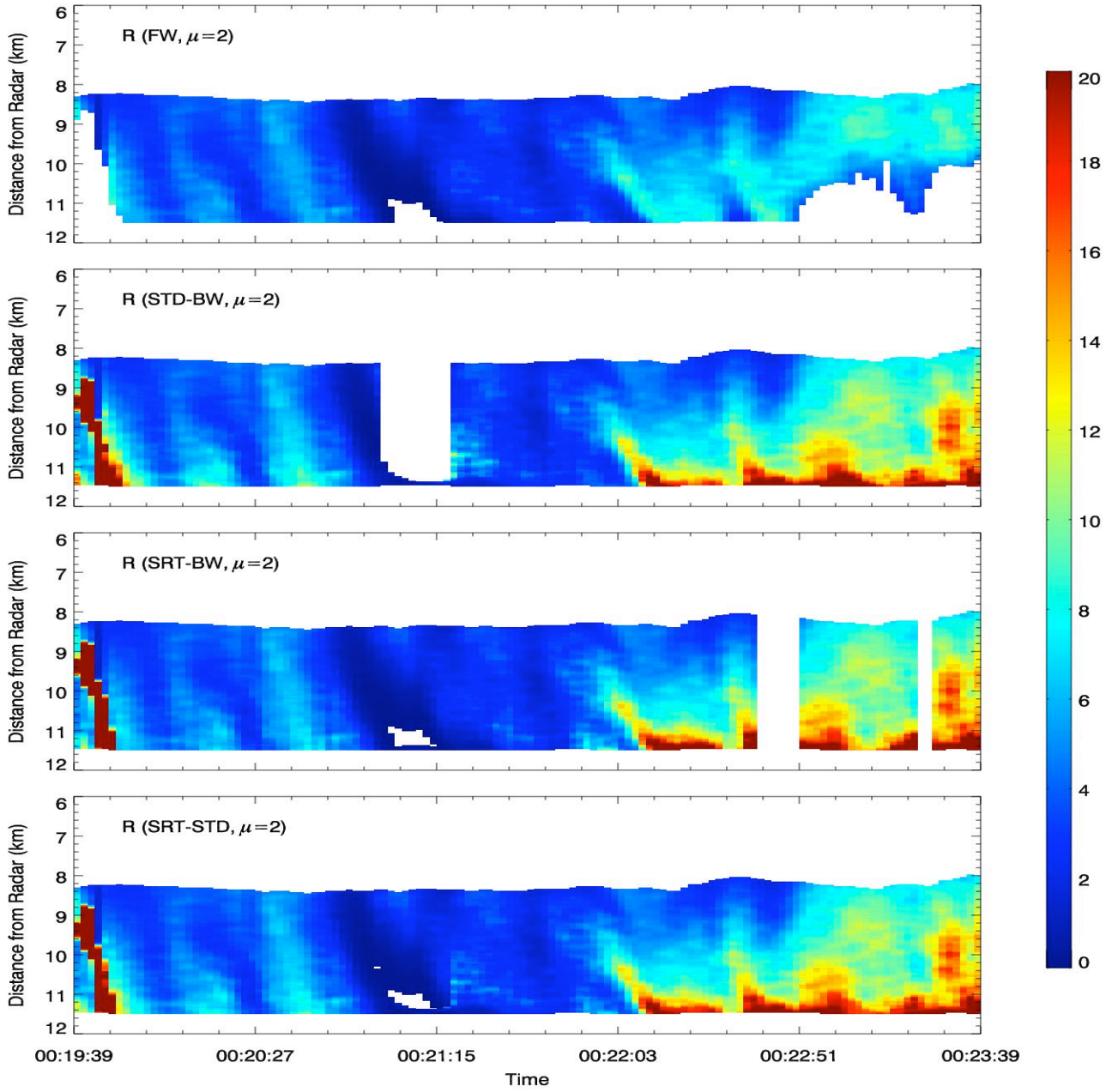
Integral Eq.

forward

backward - dod

backward - SRT

simple hybrid



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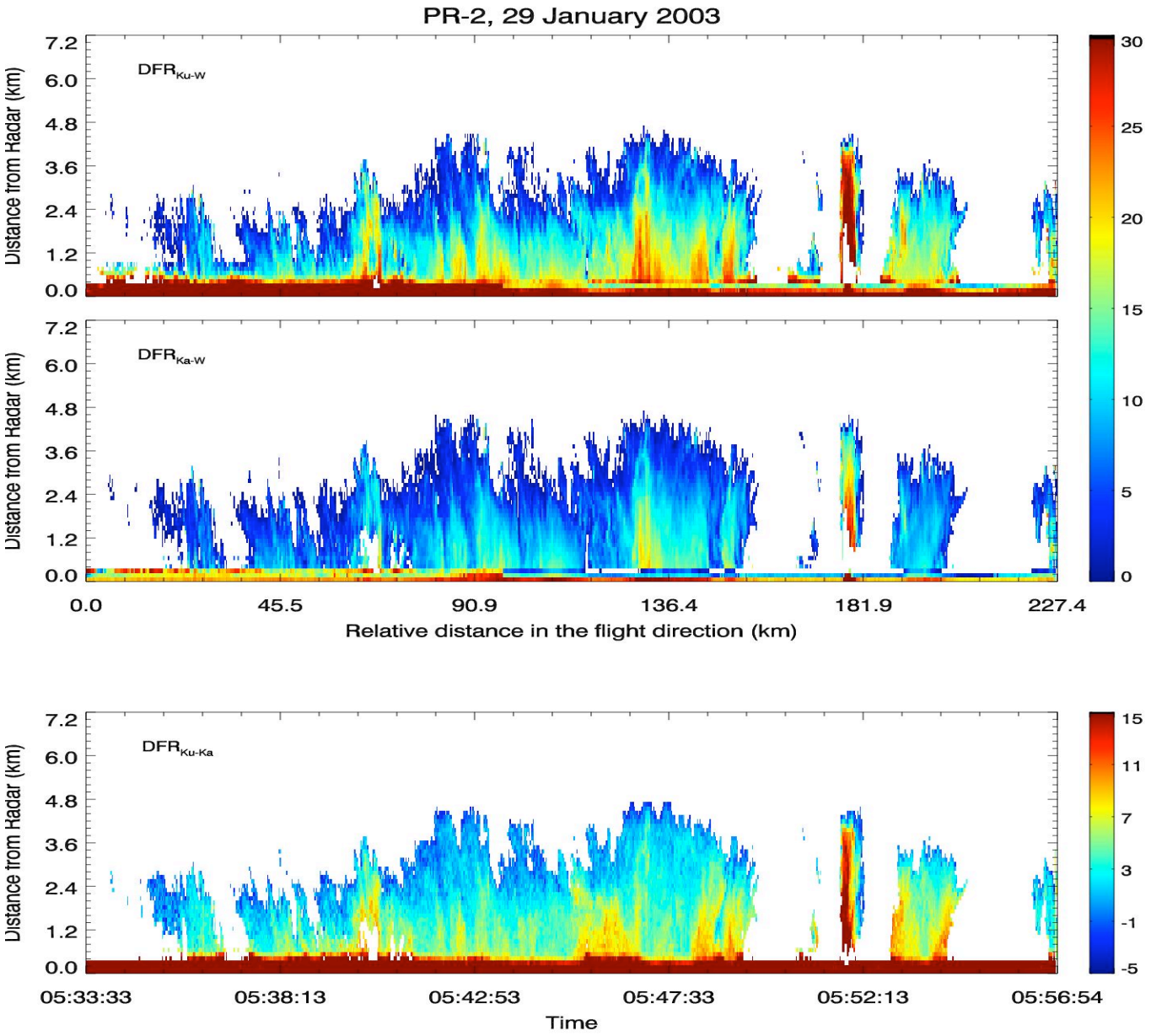
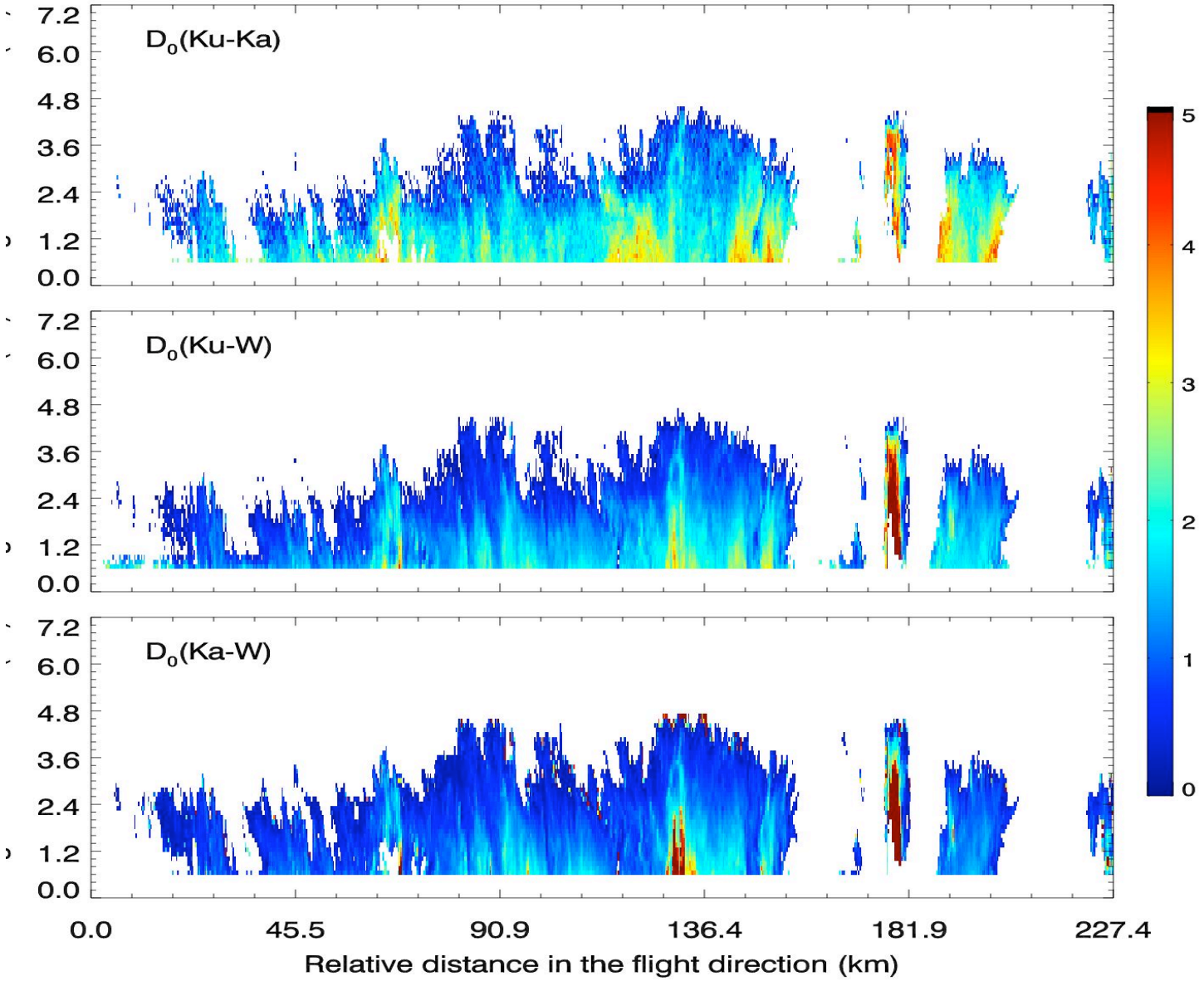
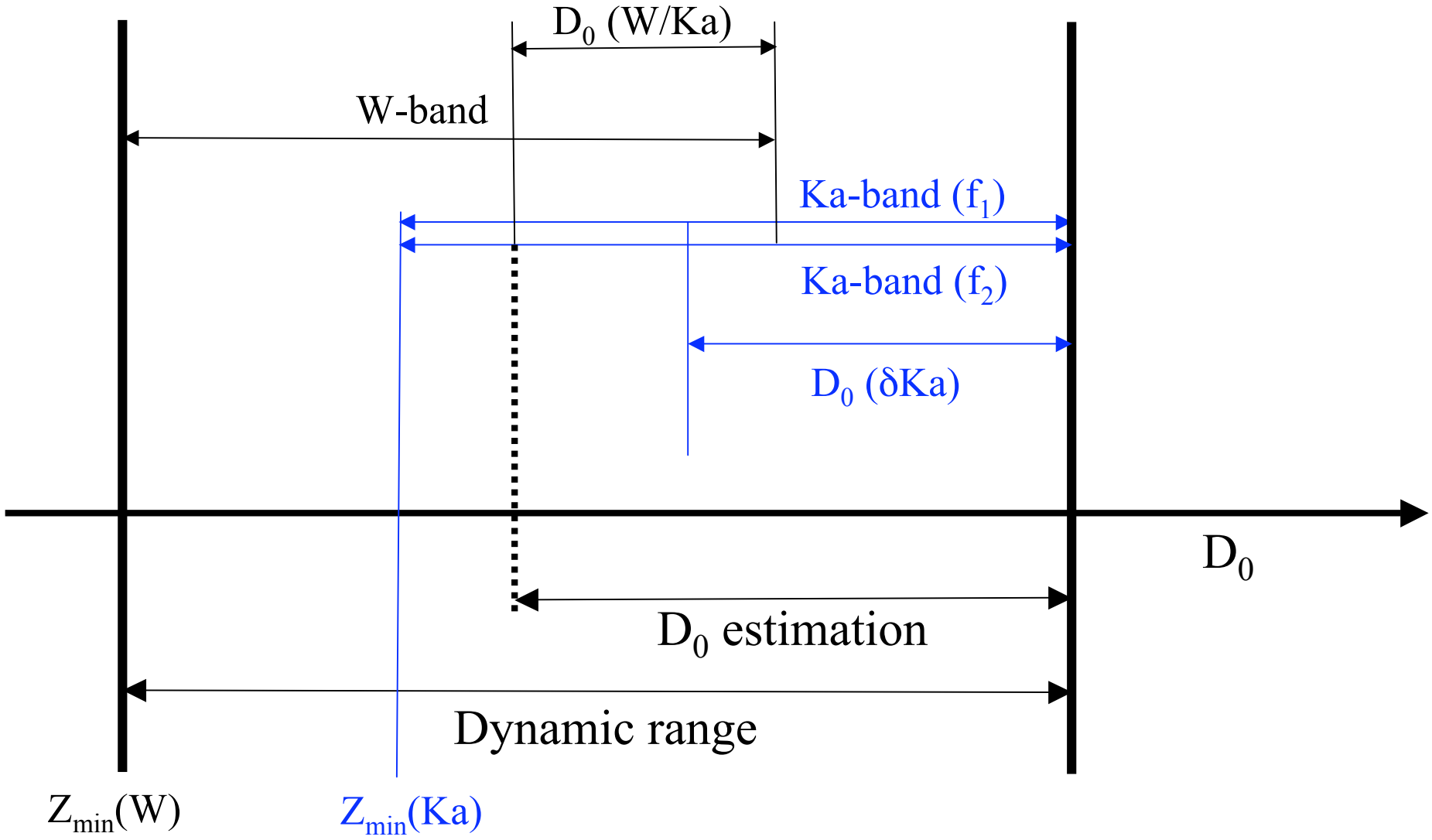
Ku-band

Ka-band

W-band




D0(Ku-Ka)
D0(Ku-W)
D0(Ka-W)
7.2
6.0
4.8
3.6
2.4
1.2
0.0
0.0
45.5
90.9
136.4
181.9
227.4
Relative distance in the flight direction (km)
5
4
3
2
1
0


D0 (W/Ka)
W-band
Ka-band (f1)
Ka-band (f2)
D0 (δKa)
D0
D0 estimation
Dynamic range
Zmin(W)
Zmin(Ka)

Development, testing & validation

- *Use of measured/assumed DSD with simplified radar model*
  - *Study basic characteristics of methods*
  - *Sensitivity to errors in PIA, radar calibration, μ parameter of DSD*
- *Use of CRM, surface & radar models*
  - *Effects of partial beamfilling, errors in SRT, beam mismatches, finite # samples*
  - *Effects of cloud water, water vapor, mixed phase*
  - *Provides comparisons of ground-based, spaceborne simulated measurements & retrievals*
- *Use of ground-based & airborne data sets*

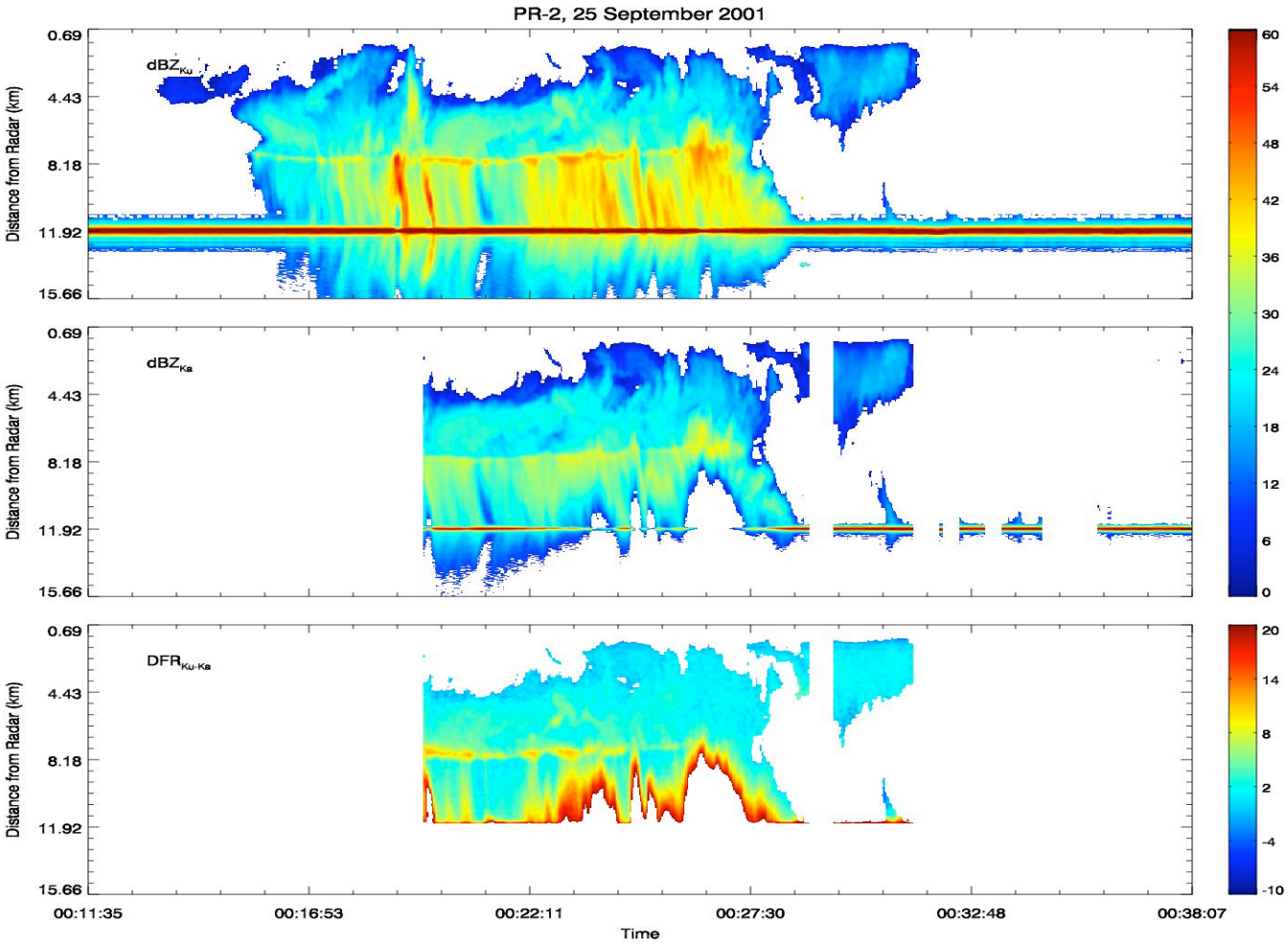
JPL PR-2, CAMEX-4: 25 Sept 2001

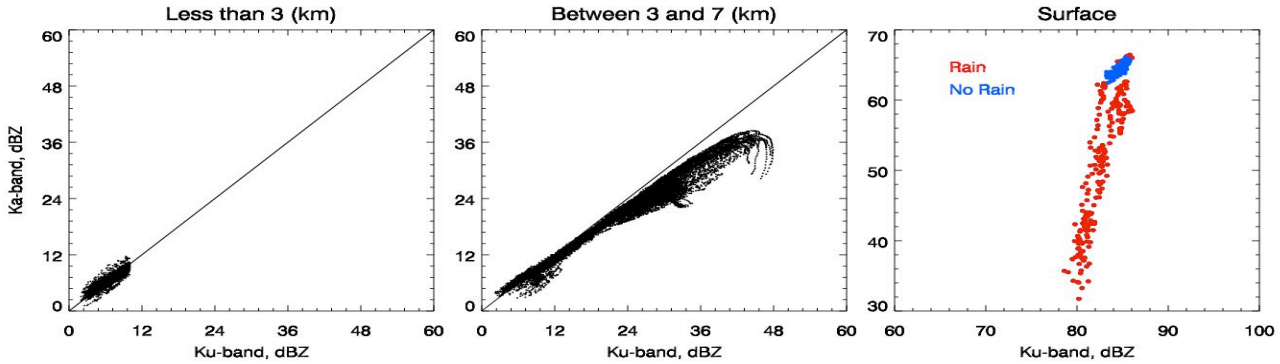
Ku-band

Ka-band

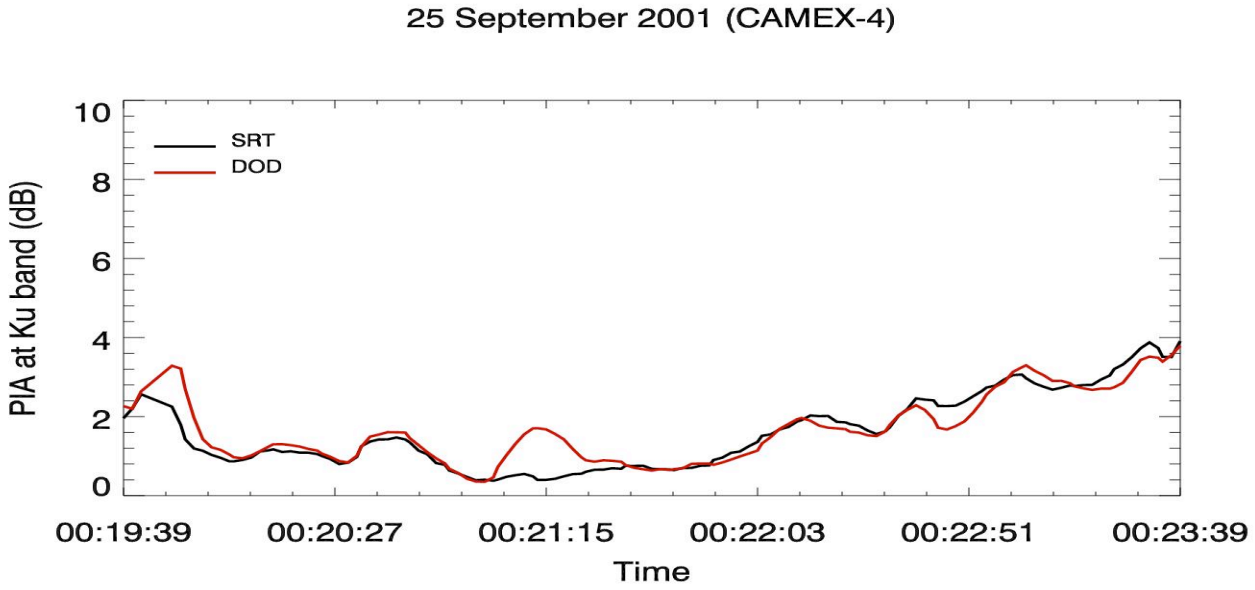
DFR

Surface return





Ku-band PIA



Ka-band PIA